Reconstructing Neutron Scatters in XENON1T

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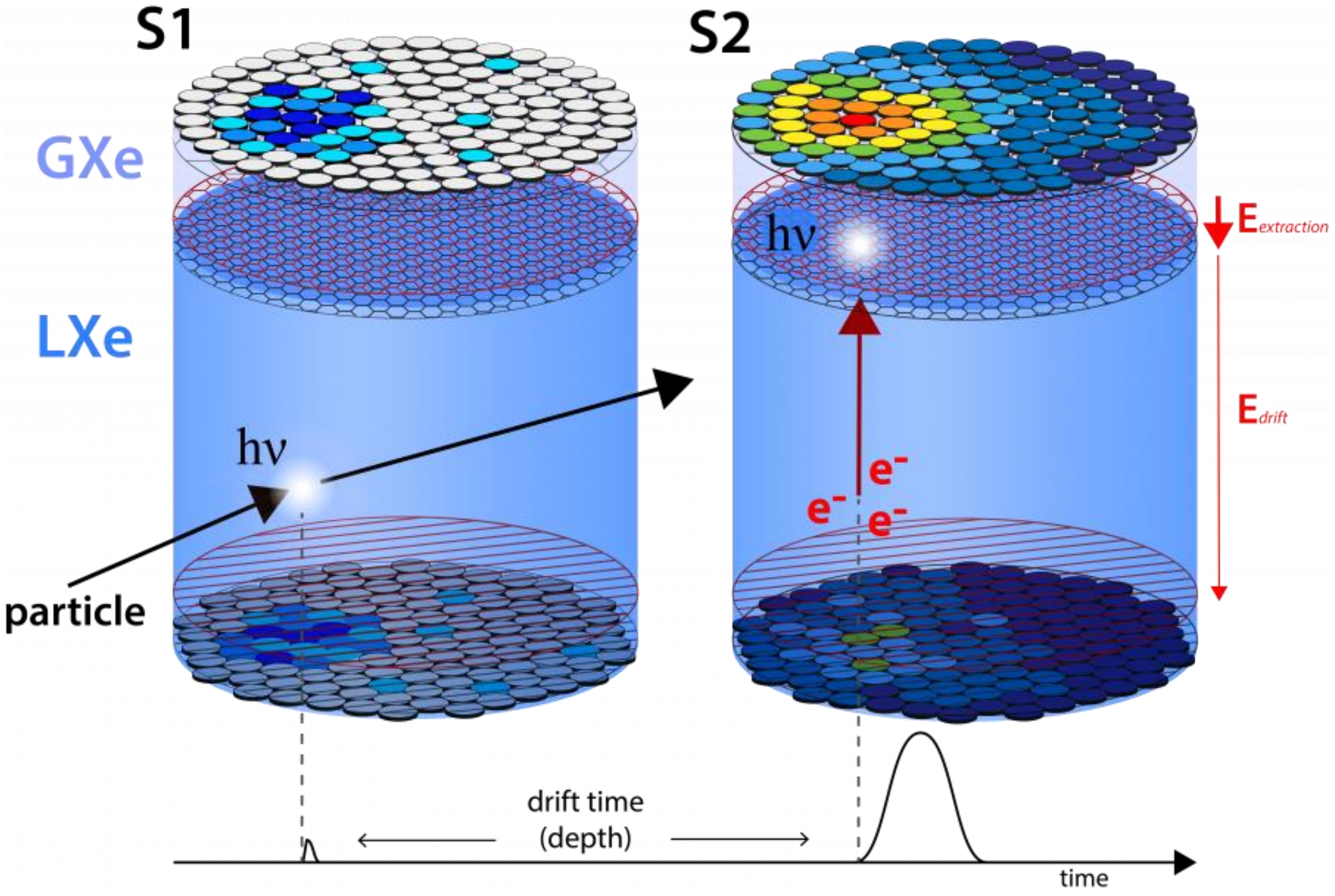
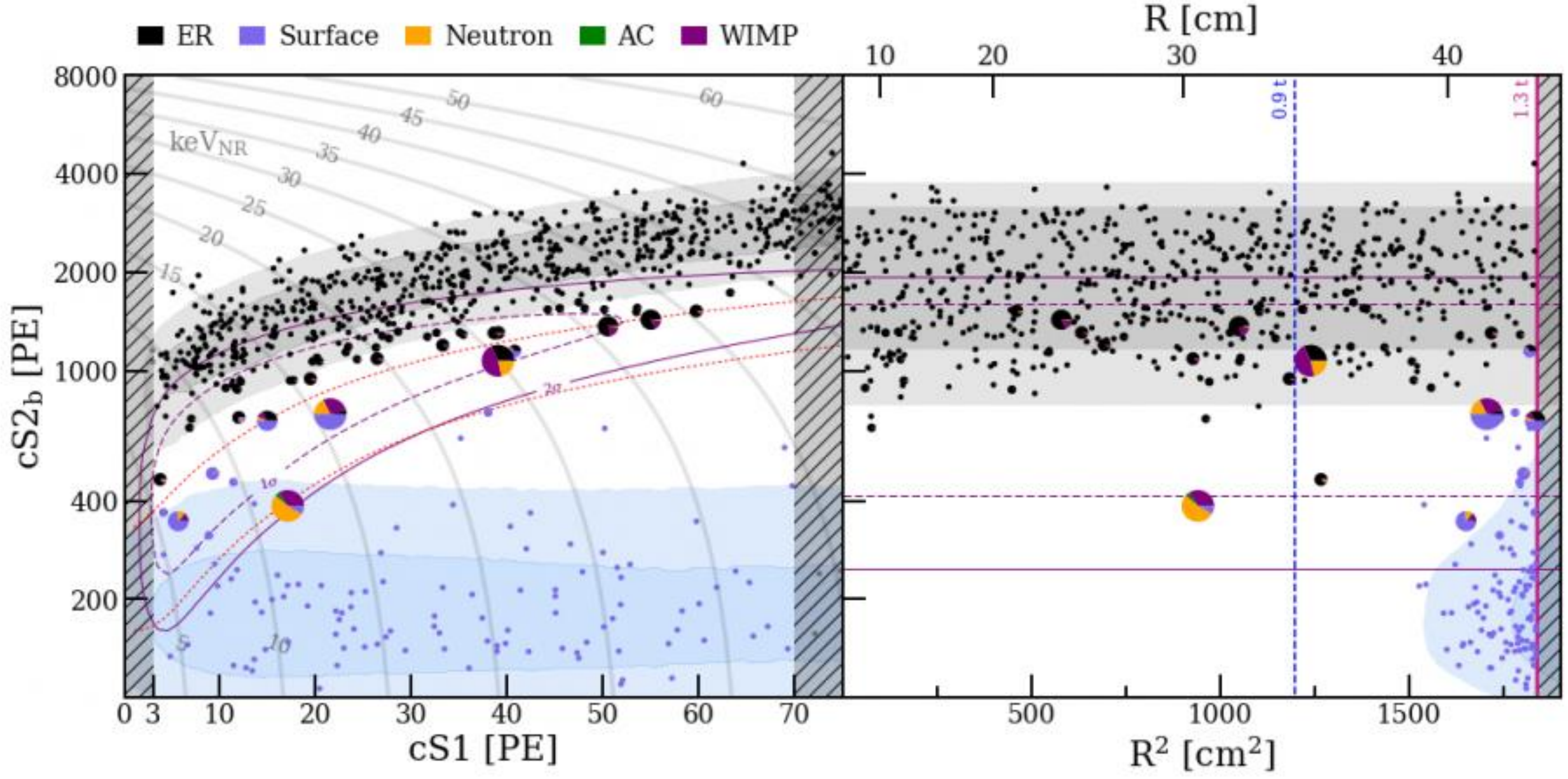
The XENON1T Experiment

Charge and Scintillation Signals in XENON1T

- An incoming Particle deposits energy on the liquid xenon target, generating an initial scintillation signal, S1
- Charge is also liberated in the interaction, and is drifted to the top of the detector with an E field where it creates a second scintillation signal, S2, in the gas phase.
- X, Y are reconstructed using the S2/S1 hit pattern. While Z is found from the time interval between S1-S2





Interpreting S1 and S2 for Electronic and Nuclear Recoils

- ER / NR events differ in charge and light yields, this allows for discrimination between types of interactions based on the ratio of S1 and S2.
- A good understanding of these charge and light yields arises from calibration sources, theoretical models, and simulation.

Charge and Light Yields in Theory

- For Helium and Argon, a good understanding of interaction cross sections allows for precise predictions of charge and light yields. Unfortunately, these cross sections have never been measured or calculated in the case of liquid xenon, making purely theoretical calculations impossible.

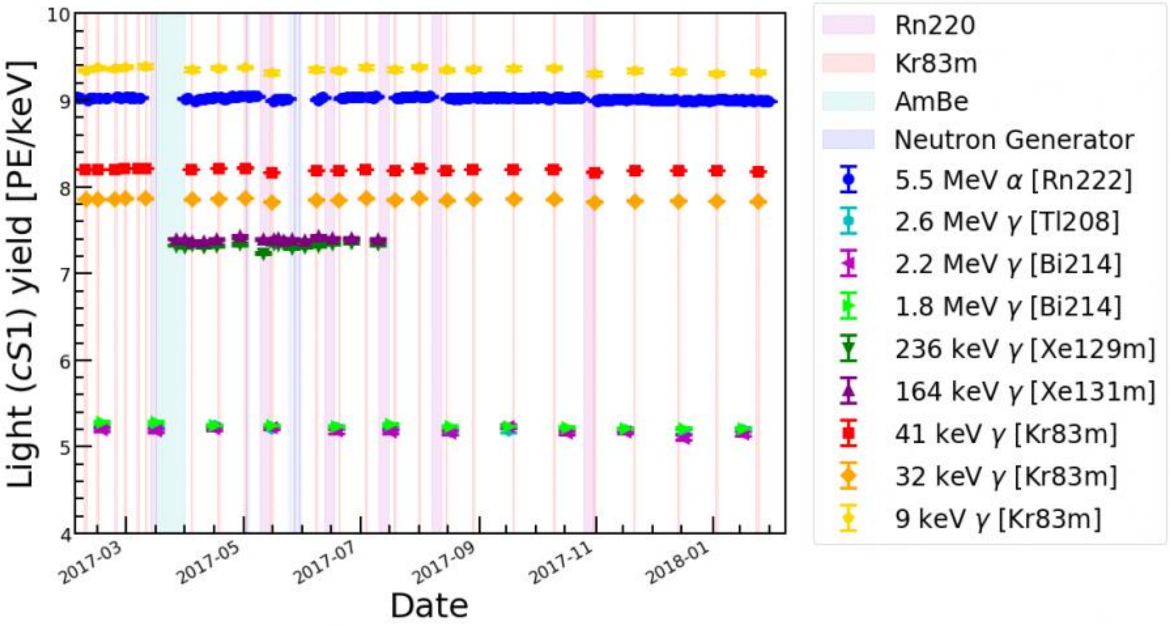
- A somewhat incomplete model for energy deposition in NRs can be formulated in the following manner:
  - The total number of quanta is given simply in terms of average energy per quantum W, deposited energy E0, and nuclear quenching factor L given by Lindhard's theory.

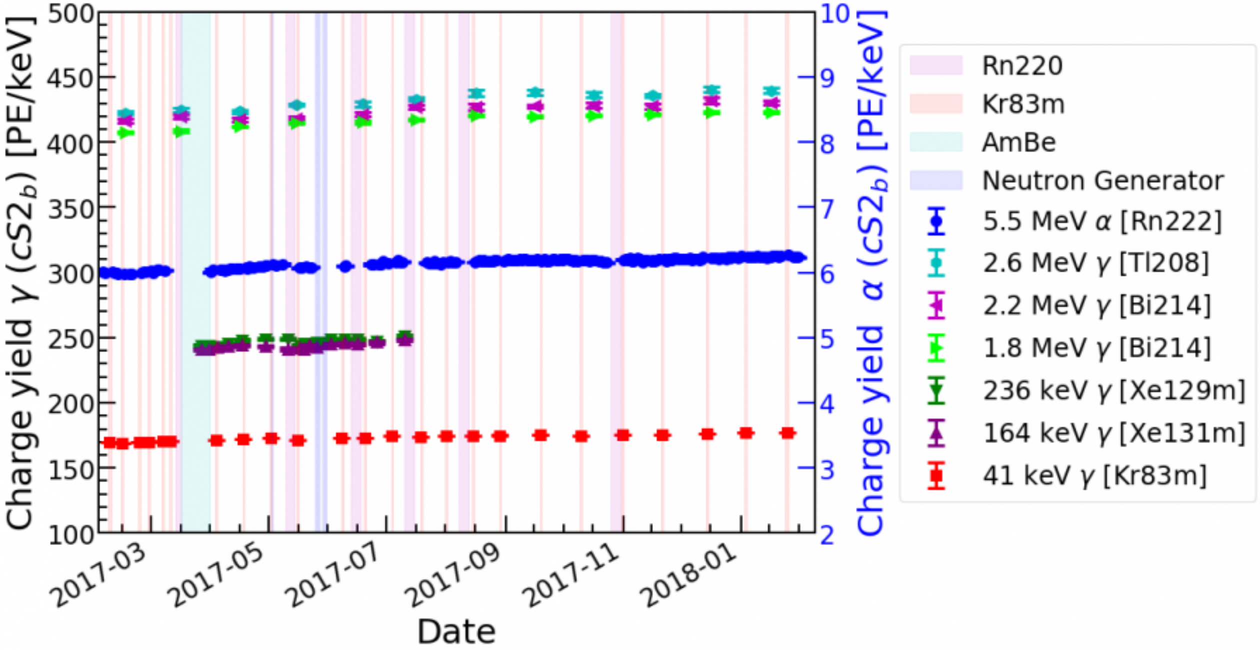
$$n_q = \frac{E_0 L}{W} = N_{ex} + N_i$$

$$L = \frac{k g(\epsilon)}{1 + k g(\epsilon)}$$

$g(\epsilon)$ proportional to the ratio of electronic and nuclear stopping power

  - This model becomes more accurate with the introduction of the exciton-ion recombination probability and Penning effects. Many additional parameters must be introduced, which are then constrained using Simulated Annealing, and Metropolis-Hastings Markov Chain Monte Carlo.





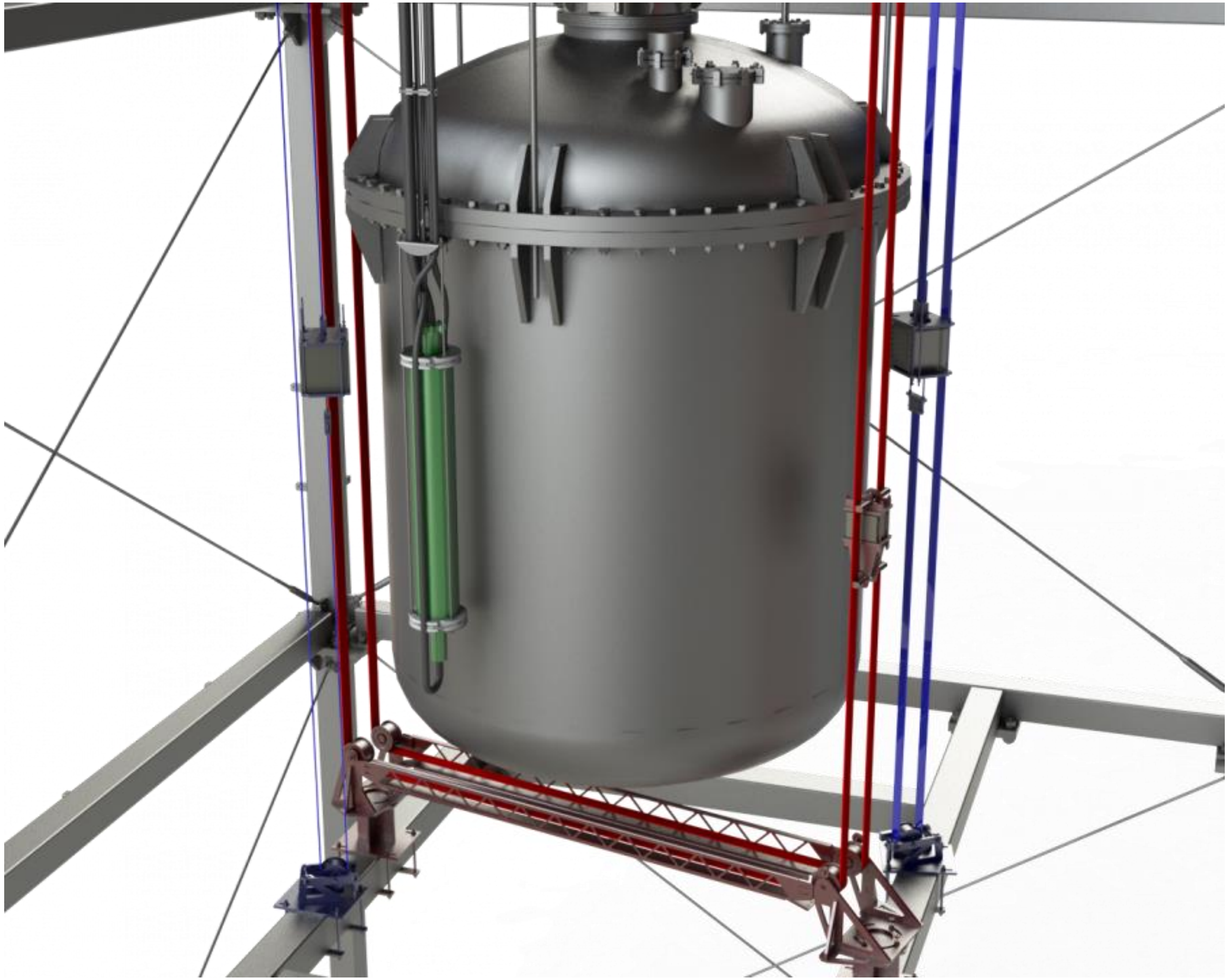
Charge and Light Yields from Data

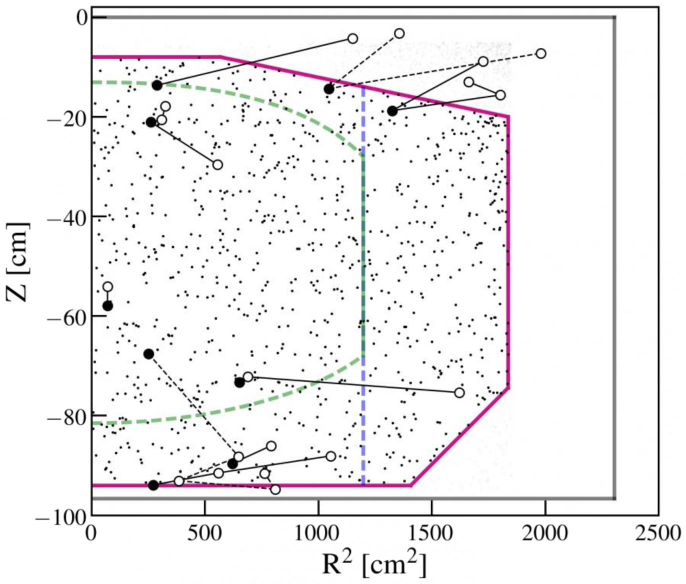
- Many radioactive sources are utilized by the XENON1T experiment in order to investigate charge and light yields, calibrate the detector, and characterize backgrounds. Most relevant to this work is a mono-energetic neutron source via deuterium-deuterium plasma fusion,
- Shown above are the results of charge and light yield measurements for a variety of sources.

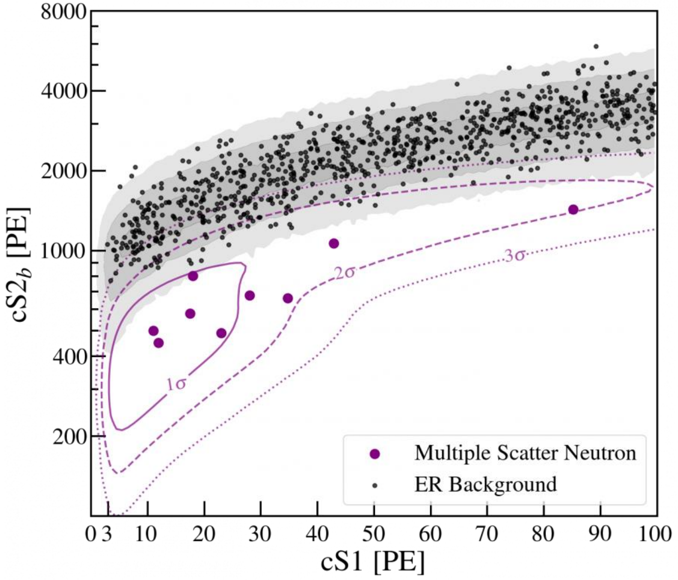
Obtaining a Better Understanding of Energy Deposition in Nuclear Recoils via Monoenergetic Neutron Scatters

XENON1T is equipped with a mono-energetic neutron source via deuterium-deuterium plasma fusion, producing neutrons with peaks at 2.2 Mev and 2.7 Mev. These neutrons undergo kev scattering within the TPC. Unfortunately, the resulting recoils are not monoenergetic, motivating a kinematic analysis of energy deposition. If these scatters can be properly reconstructed (direction and multiplicity) the energy deposited in the interaction could be known precisely. Thus leading to a better constrained model for scintillation and ionization yields for keV nuclear recoils in liquid xenon.

Monoenergetic Neutron Source in XENON

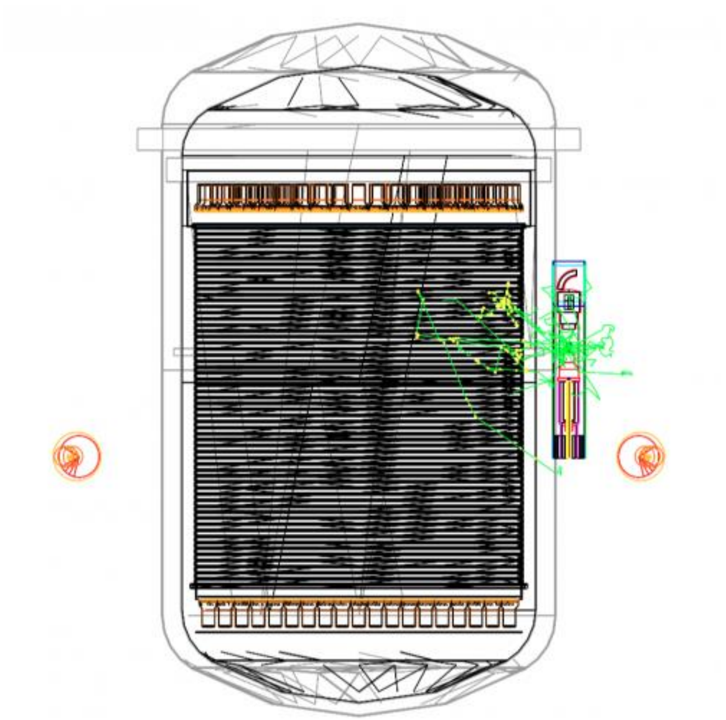


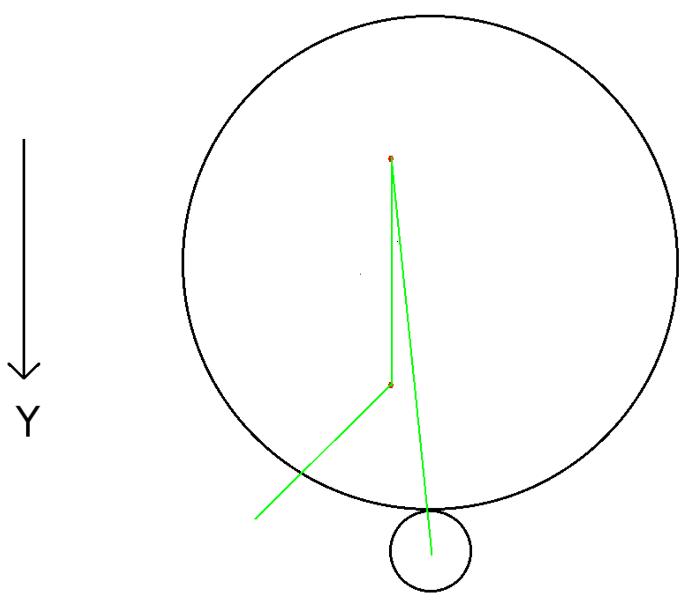


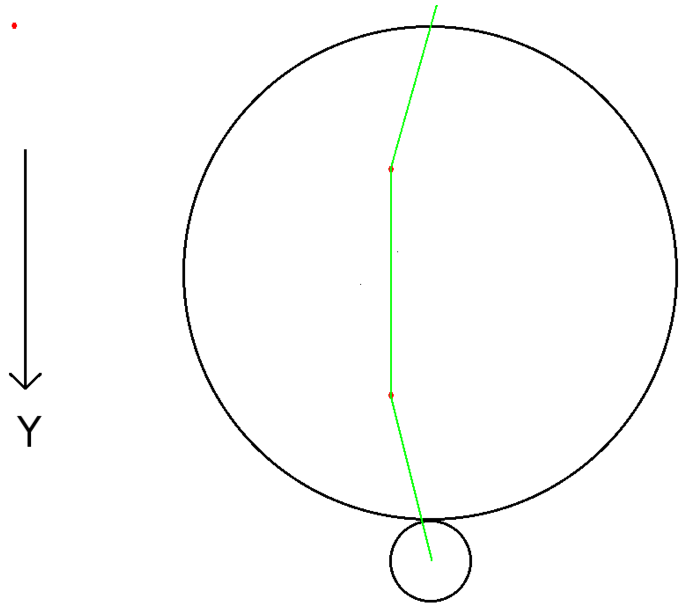


Neutron Scatters Within the Target Volume

- A single neutron may scatter multiple times in liquid xenon.
- Here we see neutrons from background sources scattering within the TPC, charge and light yields show NR's as distinct from ER's.







Difficulties in Determining Scatter Direction and Multiplicity

- Due to a mean free path of 8cm, the mean time between scatters is ~4ns. This is very close to the 10ns limit imposed by the 100Mhz digitizers used in XENON1T. This 10ns limit is in reality worsened by a variety of factors, thus the ordering of scatters in time cannot be resolved by the detector.
- Determining directionality is difficult, since either scatter has significant probability to be the first scatter

Analysis of Multiple Neutron Scatters Moving Forward

- Machine learning applications have recently proven useful in identifying scatter multiplicity for neutron scatters from background sources. A similar method adapted to this research may produce valuable results.
- Careful event selection and statistics could result in proper reconstruction of multiple neutron scatters.
- XENON1T may obtain a collimated neutron source in the near future, this would greatly ease the task of ordering multiple scatters.